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**Instrumentation Injection for  
Common Language Runtime**

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## Instrumentation Injection for 2 Common Language Runtime

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### **TECHNICAL FIELD**

6 This disclosure relates in general to reliability testing for code and in  
7 particular, by way of example but not limitation, to injecting instrumentation  
8 instructions into code with regard to a common language runtime (CLR)  
9 environment.

10

### **BACKGROUND**

11 Computer programs impact every phase of modern life from  
12 communication to transportation, from entertainment to education, from finance to  
13 manufacturing, and so forth. As evident from personal productivity desktop  
14 applications, for example, features and abilities provided by computer programs  
15 are constantly expanding and increasing. Concomitantly, the size and complexity  
16 of such computer programs is also expanding and increasing. The larger size and  
17 greater complexity of modern computer programs present ever-increasing  
18 challenges to the software engineers that are responsible for producing error-less  
19 and trouble-free software code.

20 Some software engineers are charged with testing such software code to  
21 ensure high reliability. They attempt to test every facet of the software code in as  
22 many different operational phases and situations as possible, which is a daunting if  
23 not genuinely unbounded goal. Unfortunately, this reliability testing is further  
24 exacerbated by the multitude of different programming environments, each of

1 which may introduce additional individual picayune requirements. Accordingly,  
2 there is a need for schemes and techniques that facilitate software code testing in  
3 one or more diverse programming environments, such as a CLR environment.

4

5 **SUMMARY**

6 In an exemplary media implementation, one or more processor-accessible  
7 media include processor-executable instructions that, when executed, direct a  
8 device to perform actions including: determining if an instruction of a line of  
9 common intermediate language code meets a predetermined exception-related  
10 criterion; and if so, injecting a decision point in association with the instruction of  
11 the line of common intermediate language code, the decision point enabling a  
12 decision as to whether an exception is to be thrown with respect to the instruction.

13 In an exemplary device implementation, a device includes: instrumented  
14 common intermediate language code that includes a test couplet corresponding to  
15 a decision point and an associated instruction, the associated instruction capable of  
16 causing a fault; a decision runtime library that is adapted to evaluate the test  
17 couplet to selectively decide whether to throw an exception with respect to the  
18 associated instruction; and a common language runtime component that interprets  
19 the decision point so as to call the decision runtime library prior to executing the  
20 associated instruction.

21 Other method, system, apparatus, approach, application programming  
22 interface (API), device, procedure, media, scheme, technique, arrangement, etc.  
23 implementations are described herein.

**1      BRIEF DESCRIPTION OF THE DRAWINGS**

**2**      The same numbers are used throughout the drawings to reference like  
**3** and/or corresponding aspects, features, and components.

**4**      FIG. 1 illustrates programming environments that include an exemplary  
**5** common language runtime (CLR) environment in which reliability testing for  
**6** managed code may be enabled.

**7**      FIG. 2 illustrates an exemplary approach to enabling reliability testing with  
**8** instrumentation injection and the selective throwing of exceptions.

**9**      FIG. 3 illustrates an exemplary instrumentation injection scheme including  
**10** an instrumentation tool that injects decision points.

**11**     FIG. 4 illustrates an exemplary decision point.

**12**     FIG. 5 illustrates an exemplary selective exception-throwing scheme that  
**13** includes a decision runtime library (DRL).

**14**     FIG. 6 is a flow diagram that illustrates an exemplary technique for  
**15** instrumentation injection with regard to a common language runtime environment.

**16**     FIG. 7 illustrates an exemplary computing operating environment (or  
**17** general computing device) that is capable of (wholly or partially) implementing at  
**18** least one aspect of instrumentation injection with regard to a common language  
**19** runtime environment as described herein.

**21      DETAILED DESCRIPTION**

**22**     FIG. 1 illustrates programming environments 100 that include an exemplary  
**23** common language runtime (CLR) environment 104 in which reliability testing for  
**24** managed code may be enabled 116. In addition to CLR environment 104,  
**25** programming environments 100 also include a design environment 102. In design

1 environment 102, a program designer creates source code 106. Source code 106  
2 may be produced in any of a myriad of languages, such as C++, C#, Visual Basic  
3 (VB), JScript, Cobol, Fortran, Pascal, and so forth.

4 Source code 106 undergoes compilation 108 to produce common  
5 intermediate language (CIL) code 110. Although not explicitly shown,  
6 compilation 108 of source code 106 also typically produces metadata for  
7 utilization in CLR environment 104.

8 CIL code 110 is usable as managed code in a CLR environment 104. In  
9 CLR environment 104, CIL code 110 is just-in-time (JIT) compiled 112 into native  
10 code 114. Native code 114 may be in a machine language that is processor-  
11 consumable for a particular device type. Thus, particular instruction lines of CIL  
12 code 110 are JIT compiled 112 by a CLR component 104 as the particular  
13 instruction lines are due to be executed or otherwise utilized.

14 Users prefer that CIL code 110 be errorless and trouble-free. Hence, a  
15 tester (which may be the same individual(s) as the developer of source code 106)  
16 is tasked with verifying that any exceptions that may result from executing CIL  
17 code 110 are properly handled, to the extent reasonably possible or desired,  
18 without causing a program crash (e.g., without causing a failure of a CLR  
19 component 104). In other words, loss of data, unintended program cessation, user  
20 confusion and/or inconvenience, etc. may be minimized or at least reduced with  
21 proper and thorough testing. Enabling reliability testing 116 for the managed code  
22 of CIL code 110 in CLR environment 104 is therefore described below.

23 FIG. 2 illustrates an exemplary approach to enabling reliability testing 116  
24 with instrumentation injection 208 and the selective throwing of exceptions 212.  
25 CIL code 110 (e.g., in binary form) undergoes transformation 202 and results in

1 instrumented CIL code 204. Generally, transformation 202 accepts as input CIL  
2 code 110 and injects 208 decision points 206 into such code to produce  
3 instrumented CIL code 204. This instrumented CIL code 204 can persist on disk  
4 and need not be created on-the-fly.

5 Specifically in a described implementation, for each line of CIL code 110  
6 that includes an instruction which may cause an exception, transformation 202  
7 causes a decision point 206 to be injected 208 thereat. Injecting 208 decision  
8 points 206 into CIL code 110 thus produces instrumented CIL code 204. Each  
9 decision point 206 serves as a bookmark for an instruction that may result in an  
10 exception and that can therefore be evaluated (e.g., considered for further analysis)  
11 during an execution phase of reliability testing.

12 In an execution phase of reliability testing, instrumented CIL code 204 is  
13 JIT compiled and executed 210. During execution 210, an exception can be  
14 selectively thrown 212 at each decision point 206 of instrumented CIL code 204.  
15 An exemplary instrumentation tool for injection 208 of decision points 206 is  
16 described further below with reference to FIG. 3. An exemplary decision point  
17 206 is described further below with reference to FIG. 4. And an exemplary  
18 decision runtime library (DRL) for selectively throwing exceptions 212 is  
19 described further below with reference to FIG. 5.

20 FIG. 3 illustrates an exemplary instrumentation injection scheme 116A  
21 including an instrumentation tool 304 that injects 208 decision points 206.  
22 Instrumentation tool 304 causes decision points 206 to be injected 208 into  
23 instrumented CIL code 204 at certain lines of code. Instrumented CIL code 204  
24 includes multiple (e.g., tens, hundreds, thousands, or more) lines of such code.  
25

1        As illustrated, each line of code may include an instruction 302. If  
2 execution of instruction 302 can result in an exception, instrumentation tool 304  
3 causes a decision point 206 to be injected 208 into instrumented CIL code 204  
4 (e.g., immediately) prior to instruction 302.

5        Decision point 206 and instruction 302 together form a test couplet 308 that  
6 are evaluated during an execution phase of reliability testing. Instrumentation at  
7 the CIL instruction level, as opposed to at a source code level, can increase  
8 reliability testing flexibility, can expand the applicability of reliability testing to a  
9 greater number of languages without language-specific tailoring, can permit  
10 exception targeting to a finer degree, and so forth.

11      Generally, instrumentation tool 304 is capable of progressing through  
12 instrumented CIL code 204 and analyzing each instruction 302 thereof to  
13 determine if it meets a predetermined exception-related criterion. If so,  
14 instrumentation tool 304 is adapted to inject 208 a decision point 206 into  
15 instrumented CIL code 204 in association with instruction 302 (e.g., as a  
16 corresponding test couplet 308).

17      In a described implementation, instrumentation tool 304 determines if each  
18 instruction 302 meets a predetermined exception-related criterion by determining  
19 if instruction 302 can result in an exception with reference to CIL specification  
20 306. CIL specification 306, possibly in addition to other information, lists  
21 available and/or possible instructions for CIL code 110 and indicates which  
22 instructions can result in an exception. Furthermore, CIL specification 306  
23 indicates what type(s) of exceptions can be thrown for each listed instruction.

24      Using CIL specification 306 is one (relatively exhaustive) manner for  
25 determining whether a given instruction comports with a predetermined exception-

1 related criterion. Alternatively, instructions may be considered as meeting the  
2 predetermined exception-related criterion if they are known to be prone to failure.  
3 For example, instructions that allocate memory are prone to resulting in  
4 exceptions. Memory allocation instructions include “newobj”, “box”, “callvirt”,  
5 and so forth. Thus, memory allocations may be considered a category of likely  
6 exceptions. Other exception categories include security-related instructions, disk  
7 input/output calls, arithmetic overflow, divide by zero, missing method exception,  
8 type load exception, and so forth.

9 FIG. 4 illustrates an exemplary decision point 206. Decision point 206 is  
10 implemented as one or more injected lines of code. As illustrated, decision point  
11 206 includes a bookmark entry 402 and a call to DRL 404. During an execution  
12 phase of reliability testing, when call to DRL 404 is encountered in instrumented  
13 CIL code 204, CLR component 104 passes control to a DRL module, which is  
14 described further below with reference to FIG. 5. The DRL module uses  
15 bookmark entry 402 when selectively deciding whether to throw an exception with  
16 respect to an associated instruction 302 (of FIG. 3) of a corresponding test couplet  
17 308.

18 In a described implementation, bookmark entry 402 includes an instruction  
19 type indicator 402A and an identifier 402B. Instruction type indicator 402A  
20 indicates the type of instruction of the associated instruction 302. The instruction  
21 type may be indicated by a name, a numeral, an alphanumeric variable generally,  
22 some combination thereof, and so forth. Identifier 402B comprises a value that  
23 uniquely identifies each decision point 206. For example, identifier 402B may be  
24 formed from an incrementing counter.

1        An exemplary decision point 206 is described now in the context of a  
2 “divide instruction” that can cause an exception if CIL code 110 attempts to divide  
3 by zero. For an original CIL stream (e.g., from CIL code 110):

4                ...  
5                “Divide Dividend by Divisor”  
6                ...

7        For an instrumented CIL stream (e.g., from instrumented CIL code 204):

8                ...  
9                ldc.i4 ABCxMNO <sup>[1]</sup>  
10          call void DRL module <sup>[2]</sup>  
11          “Divide Dividend by Divisor”  
12          ...

13        In the exemplary instrumented CIL stream above, two instruction lines [1]  
14 and [2] are used to realize decision point 206. The first line [1] implements  
15 bookmark entry 402, and the second line [2] implements call to DRL 404. The  
16 first line [1] loads a code ABCxMNO that jointly includes both instruction type  
17 indicator 402A and identifier 402B, with “ABC” representing instruction type  
18 indicator 402A and “MNO” representing identifier 402B. Alternatively, bookmark  
19 entry 402 may be implemented with two separate lines, one for each of instruction  
20 type indicator 402A and identifier 402B. The second line [2] makes a call to the  
21 DRL module; it includes ‘void’ so that the lines of instrumentation (e.g., decision  
22 points 206) do not affect the overall programmatic execution.

23        FIG. 5 illustrates an exemplary selective exception-throwing scheme 116B  
24 that includes a DRL 502. During JIT compiling/execution 210 of instrumented  
25 CIL code 204 by CLR component 104, injected decision points 206 are reached

1 from time to time. When a decision point 206 is detected, DRL 502 is called (e.g.,  
2 as a result of a call to DRL 404).

3 In a described implementation, DRL 502 is adapted to selectively decide  
4 whether to throw an exception (e.g., induce a failure) for an instruction 302 (of  
5 FIG. 3) that is associated with decision point 206 as part of a corresponding test  
6 couplet 308. If an exception is thrown, DRL 502 consequently simulates an  
7 appropriate error condition in order to enable the testing of CIL code 110 for  
8 reliability. For example, an out of memory error condition can be induced for a  
9 decision point 206 that is associated with a memory allocation type of instruction  
10 302. DRL 502 makes a selective decision regarding whether to throw an  
11 exception responsive to bookmark entry 402, which includes instruction type  
12 indicator 402A and identifier 402B.

13 DRL 502 may be implemented in any of many manners, including  
14 extensible manners. For example, DRL 502 may be capable of handling any  
15 exception category and any instruction type. Alternatively, DRL 502 may be  
16 targeted for one or more specific exception categories and/or one or more specific  
17 instruction types. Thus, as indicated in FIG. 5, DRLs 502 may optionally be  
18 targeted by exception area. For example, they may be modularized by exception  
19 category and/or dependent on instruction type. This permits program testers with  
20 individual testing interests or tasks to focus on desired exception areas when  
21 testing the reliability of a particular CIL code 110/instrumented CIL code 204.

22 As illustrated, DRL 502 is capable of making a selective decision regarding  
23 whether to throw an exception responsive to bookmark entry 402 and based on at  
24 least one throw exception decision (TED) logic factor 504. Although three  
25 exemplary TED logic factors 504(1, 2, 3) are shown, four or more TED logic

1 factors 504 may alternatively be employed by DRL 502 either individually or  
2 jointly.

3 TED logic factor 504(1) causes a decision regarding whether to throw an  
4 exception to be made based on a random determination. For example, DRL 502  
5 may be configured such that it induces a fault on a particular instruction type, as  
6 indicated by instruction type indicator 402A, half of the time. TED logic factor  
7 504(2) causes a decision regarding whether to throw an exception to be made  
8 based on whether the instruction 302 that is associated with the decision point 206  
9 that is being evaluated has been previously encountered. For example, DRL 502  
10 may be configured such that it induces a fault on a first occurrence of any given  
11 instruction 302, as identified by identifier 402B of bookmark entry 402. TED  
12 logic factor 504(3) causes a decision regarding whether to throw an exception to  
13 be made based on whether the instruction 302 that is associated with the decision  
14 point 206 that is being evaluated has been previously reached by a current  
15 program path. For example, DRL 502 may be configured such that it induces a  
16 fault a first time that a particular instruction 302 is reached from a particular  
17 calling routine.

18 Hence, DRL 502 may utilize any one or more of many possible exemplary  
19 TED logic factors 504, including those illustrated in FIG. 5. Additional TED logic  
20 factor 504 examples follow. For example, DRL 502 can always induce a fault at  
21 each decision point 206 for all instruction types or a subset thereof. As another  
22 example, DRL 502 can factor into the exception decision selectivity evaluation  
23 what method was previously called. As yet another example, DRL 502 can  
24 ascertain at what location instrumented CIL code 204 is being executed from a  
25 programmatic perspective. A stack walk can be performed to ascertain who the

1 previous caller is. This TED logic factor 504 may be employed when a particular  
2 instruction 302, and its associated decision point 206 for a corresponding test  
3 couplet 308, may be encountered in two programmatic locations and a failure is to  
4 be induced at each calling.

5 Transformation 202 (at FIG. 2) of CIL code 110 to produce instrumented  
6 CIL code 204 thus introduces a new dependency for the execution thereof. In  
7 other words, to execute the binary form of instrumented CIL code 204 (at least  
8 when performing reliability testing thereon), DRL 502 is utilized in addition to any  
9 other libraries that are already utilized when executing the binary form of CIL  
10 code 110.

11 FIG. 6 is a flow diagram that illustrates an exemplary technique 116\* for  
12 instrumentation injection with regard to a common language runtime environment.  
13 The flow diagram of exemplary technique 116\* includes twelve (12) blocks 602-  
14 620 (including blocks 606A and 606B). Although the actions of these blocks 602-  
15 620 may be performed in other implementations, FIGS. 2-5 are used in particular  
16 to illuminate certain aspects of the technique.

17 For example, the flow diagram of exemplary technique 116\* is divided into  
18 three parts: instrumentation tool 304, CLR component 104, and DRL module 502.  
19 As illustrated, instrumentation tool 304 performs the actions of blocks 602-610,  
20 CLR component 104 performs the actions of blocks 612-614, and DRL module  
21 502 performs the actions of blocks 616-620. Although illustrated separately, one  
22 or more modules for DRL 502 may actually be executing within, as part of, and/or  
23 in conjunction with a CLR environment 104.

24 At block 602, a line of CIL code that has an instruction is retrieved. For  
25 example, a line of code that includes instruction 302 may be retrieved from CIL

1 code 110 by instrumentation tool 304. At block 604, it is determined if the  
2 retrieved instruction is capable of causing an exception. For example,  
3 instrumentation tool 304 may determine if the retrieved instruction 302 can result  
4 in an exception (e.g., when executed by a CLR component 104) with reference to  
5 CIL specification 306.

6 As described above with reference to FIG. 5, DRL 502 can be configured to  
7 throw an exception based on instruction type. Similarly, instrumentation tool 304  
8 can be configured to instrument a subset of those instructions 302 that meet a  
9 predetermined exception-related criterion. In other words, instrumentation tool  
10 304 specifically, and instrumentation injection scheme 116A generally, may be  
11 configured to inject 208 decision points 206 for a particular instruction or set of  
12 instructions and/or a particular exception category. The determination action of  
13 block 604 can therefore entail determining whether the retrieved instruction is to  
14 be evaluated in a subsequent execution phase of reliability testing.

15 If the retrieved instruction is determined to be capable of causing an  
16 exception (at block 604), then a decision point is injected at block 606. For  
17 example, instrumentation tool 304 may inject a decision point 206 in association  
18 with the retrieved instruction 302 to form a test couplet 308. To inject the decision  
19 point (at block 606), a bookmark entry is injected at block 606A, and a DRL call is  
20 injected at block 606B. For example, as at least part of decision point 206,  
21 instrumentation tool 304 may inject bookmark entry 402 and call to DRL 404.

22 After the injection of the decision point (at block 606) or if the retrieved  
23 instruction is determined to not be capable of throwing an exception (at block  
24 604), then flow continues at block 608. At block 608, it is ascertained whether  
25 there are more lines of CIL code to be analyzed. For example, instrumentation

1 tool 304 may ascertain whether any additional lines of CIL code 110 remain to be  
2 analyzed for possible exception-throwing capabilities. If so, the next line is  
3 retrieved at block 602.

4 If, on the other hand, it is ascertained that there are no more lines of CIL  
5 code (at block 608), then flow continues at block 610. At block 610, instrumented  
6 CIL code is produced. For example, a transformation 202 that has been  
7 effectuated by instrumentation tool 304 on CIL code 110 with injection 208 of  
8 decision points 206 produces instrumented CIL code 204. This instrumented CIL  
9 code 204 may optionally be stored on disk until the execution phase of reliability  
10 testing is to begin.

11 When the execution phase of reliability testing commences, the  
12 instrumented CIL code is JIT compiled and executed. For example, instrumented  
13 CIL code 204 may be provided to CLR component 104 for JIT  
14 compiling/execution 210. Each line of the instrumented CIL code is addressed by  
15 the CLR environment. For example, each instruction line of instrumented CIL  
16 code 204 is managed by CLR component 104.

17 Eventually, at block 612, a decision point in the instrumented CIL code is  
18 detected during execution thereof. For example, CLR component 104 may detect  
19 decision point 206 in instrumented CIL code 204. At block 614, a DRL module is  
20 called. For example, because of call to DRL 404 that is part of decision point 206,  
21 CLR component 104 calls DRL module 502.

22 At block 616, it is selectively decided whether execution of the  
23 instrumented CIL code is to fail at the detected decision point. For example, DRL  
24 module 502 evaluates the detected decision point 206 responsive to bookmark  
25 entry 402 and based on at least one TED logic factor 504. If it is decided that the

1 detected decision point is not to result in a testing failure (at block 616), then flow  
2 continues at block 612 for the detection of another decision point during execution  
3 of the instrumented CIL code. For example, control may be returned to CLR  
4 component 104 so that execution of instrumented CIL code 204 may continue.

5 If, on the other hand, it is decided that the detected decision point is to  
6 result in a testing failure (at block 616), then which exception is to be thrown is  
7 chosen at block 618. For example, some instructions 302 can result in more than  
8 one type of exception being thrown (e.g., as stipulated by CIL specification 306).  
9 In such circumstances, a particular failure may be chosen that is context-  
10 appropriate, may be chosen randomly, may be chosen by exception area of  
11 concern, and so forth.

12 After the exception to be thrown is chosen (at block 618), a failure is  
13 induced at block 620. For example, DRL module 502 may induce a failure of  
14 CLR component 104 with respect to the instruction 302 that is associated with the  
15 detected decision point 206 in order to simulate an intended failure condition when  
16 testing CIL code 110 for reliability.

17 The aspects, features, schemes, etc. of FIGS. 1-5 and the technique(s) of  
18 FIG. 6, for example, are illustrated in diagrams that are divided into multiple  
19 blocks. However, the order and/or layout in which they are described and/or  
20 shown is not intended to be construed as a limitation, and any number of the  
21 blocks can be combined, rearranged, augmented, omitted, etc. in any manner to  
22 implement one or more systems, methods, devices, procedures, media, APIs,  
23 apparatuses, arrangements, etc. for instrumentation injection with regard to a  
24 common language runtime environment. Furthermore, although the description  
25 herein includes references to specific implementations such as those of FIGS. 2-6

1 (as well as the exemplary operating environment of FIG. 7), the approaches,  
2 schemes, and techniques thereof can be implemented in any suitable hardware,  
3 software, firmware, or combination thereof and using any suitable programming  
4 language(s), runtime environment(s), object-oriented paradigm(s), application  
5 programming interface(s), managed code mechanisms(s), and so forth.

6 FIG. 7 illustrates an exemplary computing operating environment 700 (or  
7 general computing device) that is capable of (fully or partially) implementing at  
8 least one system, device, media, component, approach, method, process, some  
9 combination thereof, etc. for instrumentation injection with regard to a common  
10 language runtime environment as described herein. Computing environment 700  
11 may be utilized in the computer and network architectures described below or in a  
12 stand-alone situation.

13 Exemplary computing device operating environment 700 is only one  
14 example of an environment and is not intended to suggest any limitation as to the  
15 scope of use or functionality of the applicable computing device architectures  
16 (including those of computers, consumer electronics, game consoles, set-top  
17 boxes, mobile appliances, etc.). Furthermore, computing device environment 700  
18 is not to be interpreted as having any dependency or requirement relating to any  
19 one or any combination of components as illustrated in FIG. 7. Moreover, the  
20 applicable computing devices are not limited by the processors/processing  
21 mechanisms employed therein. For example, such processors/processing  
22 mechanisms may include, but are not limited to, electronic integrated circuits  
23 (ICs), quantum computing, optical computing, mechanical computing (e.g., using  
24 nano technology), and so forth.

1        Additionally, instrumentation injection with regard to a common language  
2 runtime environment may be implemented with numerous other general purpose  
3 or special purpose computing device (including electronic device) environments or  
4 configurations. Examples of well known computing (device) systems,  
5 environments, and/or configurations that may be suitable for use include, but are  
6 not limited to, personal computers, server computers, thin clients, thick clients,  
7 personal digital assistants (PDAs) or mobile telephones, hand-held or laptop  
8 devices, multiprocessor systems, microprocessor-based systems, set top boxes,  
9 programmable consumer electronics, video game machines, game consoles,  
10 portable or handheld gaming units, network PCs, minicomputers, mainframe  
11 computers, distributed computing environments that include any of the above  
12 systems or devices, some combination thereof, and so forth.

13        Implementations for instrumentation injection with regard to a common  
14 language runtime environment may be described in the general context of  
15 processor-executable instructions. Generally, processor-executable instructions  
16 include routines, programs, objects, components, data structures, other code, etc.  
17 that perform particular tasks or implement particular abstract data types.  
18 Instrumentation injection with regard to a common language runtime environment,  
19 as described in certain implementations herein, may also be practiced in  
20 distributed computing environments where tasks are performed by remotely-linked  
21 processing devices that are connected through a communications link and/or  
22 network. Especially in a distributed computing environment, processor-executable  
23 instructions may be located in separate storage media, executed by different  
24 processors, and/or extant on or propagated over transmission media.

25

1 Computing device environment 700 includes a general-purpose computing  
2 device in the form of a computer 702, which may comprise any computing device  
3 with computing and/or processing capabilities. The components of computer 702  
4 may include, but are not limited to, one or more processors or processing units  
5 704, a system memory 706, and a system bus 708 that couples various system  
6 components including processor 704 to system memory 706.

7 System bus 708 represents one or more of any of many types of wired or  
8 wireless bus structures, including a memory bus or memory controller, a point-to-  
9 point connection, a switching fabric, a peripheral bus, an accelerated graphics port,  
10 and a processor or local bus using any of a variety of bus architectures. By way of  
11 example, such architectures may include an Industry Standard Architecture (ISA)  
12 bus, a Micro Channel Architecture (MCA) bus, an Enhanced ISA (EISA) bus, a  
13 Video Electronics Standards Association (VESA) local bus, a Peripheral  
14 Component Interconnects (PCI) bus also known as a Mezzanine bus, some  
15 combination thereof, and so forth.

16 Computer 702 typically includes a variety of processor-accessible media.  
17 Such media may be any available media that is accessible by computer 702 or  
18 another computing device, and it includes both volatile and non-volatile media,  
19 removable and non-removable media, and storage and transmission media.

20 System memory 706 includes processor-accessible storage media in the  
21 form of volatile memory, such as random access memory (RAM) 710, and/or non-  
22 volatile memory, such as read only memory (ROM) 712. A basic input/output  
23 system (BIOS) 714, containing the basic routines that help to transfer information  
24 between elements within computer 702, such as during start-up, is typically stored  
25 in ROM 712. RAM 710 typically contains data and/or program

1 modules/instructions that are immediately accessible to and/or being presently  
2 operated on by processing unit 704.

3 Computer 702 may also include other removable/non-removable and/or  
4 volatile/non-volatile storage media. By way of example, FIG. 7 illustrates a hard  
5 disk drive or disk drive array 716 for reading from and writing to a (typically)  
6 non-removable, non-volatile magnetic media (not separately shown); a magnetic  
7 disk drive 718 for reading from and writing to a (typically) removable, non-  
8 volatile magnetic disk 720 (e.g., a “floppy disk”); and an optical disk drive 722 for  
9 reading from and/or writing to a (typically) removable, non-volatile optical disk  
10 724 such as a CD-ROM, DVD-ROM, or other optical media. Hard disk drive 716,  
11 magnetic disk drive 718, and optical disk drive 722 are each connected to system  
12 bus 708 by one or more storage media interfaces 726. Alternatively, hard disk  
13 drive 716, magnetic disk drive 718, and optical disk drive 722 may be connected  
14 to system bus 708 by one or more other separate or combined interfaces (not  
15 shown).

16 The disk drives and their associated processor-accessible media provide  
17 non-volatile storage of processor-executable instructions, such as data structures,  
18 program modules, and other data for computer 702. Although exemplary  
19 computer 702 illustrates a hard disk 716, a removable magnetic disk 720, and a  
20 removable optical disk 724, it is to be appreciated that other types of processor-  
21 accessible media may store instructions that are accessible by a computing device,  
22 such as magnetic cassettes or other magnetic storage devices, flash memory, CD-  
23 ROM, digital versatile disks (DVD) or other optical storage, RAM, ROM,  
24 electrically-erasable programmable read-only memories (EEPROM), and so forth.  
25 Such media may also include so-called special purpose or hard-wired integrated

1 circuit (IC) chips. In other words, any processor-accessible media may be utilized  
2 to realize the storage media of the exemplary computing system and environment  
3 700.

4 Any number of program modules (or other units or sets of processor-  
5 executable instructions) may be stored on hard disk 716, magnetic disk 720,  
6 optical disk 724, ROM 712, and/or RAM 710, including by way of general  
7 example, an operating system 728, one or more application programs 730, other  
8 program modules 732, and program data 734. By way of specific example but not  
9 limitation, instrumentation tool 304 and DRL 502 (of FIGS. 3, 5, and 6) may be all  
10 or a portion of any one or more of such program modules 728, 730, 732, and 734.  
11 Also, instrumented CIL code 204 and optional CIL specification 306 may be all or  
12 a portion of program data 734.

13 A user may enter commands and/or information into computer 702 via  
14 input devices such as a keyboard 736 and a pointing device 738 (e.g., a “mouse”).  
15 Other input devices 740 (not shown specifically) may include a microphone,  
16 joystick, game pad, satellite dish, serial port, scanner, and/or the like. These and  
17 other input devices are connected to processing unit 704 via input/output  
18 interfaces 742 that are coupled to system bus 708. However, they may instead be  
19 connected by other interface and bus structures, such as a parallel port, a game  
20 port, a universal serial bus (USB) port, an IEEE 1374 (“Firewire”) interface, an  
21 IEEE 802.11 wireless interface, a Bluetooth® wireless interface, and so forth.

22 A monitor/view screen 744 or other type of display device may also be  
23 connected to system bus 708 via an interface, such as a video adapter 746. Video  
24 adapter 746 (or another component) may be or may include a graphics card for  
25 processing graphics-intensive calculations and for handling demanding display

1 requirements. Typically, a graphics card includes a graphics processing unit  
2 (GPU), video RAM (VRAM), etc. to facilitate the expeditious performance of  
3 graphics operations. In addition to monitor 744, other output peripheral devices  
4 may include components such as speakers (not shown) and a printer 748, which  
5 may be connected to computer 702 via input/output interfaces 742.

6 Computer 702 may operate in a networked environment using logical  
7 connections to one or more remote computers, such as a remote computing device  
8 750. By way of example, remote computing device 750 may be a personal  
9 computer, a portable computer (e.g., laptop computer, tablet computer, PDA,  
10 mobile station, etc.), a palm or pocket-sized computer, a gaming device, a server, a  
11 router, a network computer, a peer device, other common network node, or  
12 another computer type as listed above, and so forth. However, remote computing  
13 device 750 is illustrated as a portable computer that may include many or all of the  
14 elements and features described herein with respect to computer 702.

15 Logical connections between computer 702 and remote computer 750 are  
16 depicted as a local area network (LAN) 752 and a general wide area network  
17 (WAN) 754. Such networking environments are commonplace in offices,  
18 enterprise-wide computer networks, intranets, the Internet, fixed and mobile  
19 telephone networks, other wireless networks, gaming networks, some combination  
20 thereof, and so forth. Such networks and communications connections, as well as  
21 the underlying physical hardware, are examples of transmission media.

22 When implemented in a LAN networking environment, computer 702 is  
23 usually connected to LAN 752 via a network interface or adapter 756. When  
24 implemented in a WAN networking environment, computer 702 typically includes  
25 a modem 758 or other means for establishing communications over WAN 754.

1 Modem 758, which may be internal or external to computer 702, may be  
2 connected to system bus 708 via input/output interfaces 742 or any other  
3 appropriate mechanism(s). It is to be appreciated that the illustrated network  
4 connections are exemplary and that other means of establishing communication  
5 link(s) between computers 702 and 750 may be employed.

6 In a networked environment, such as that illustrated with computing device  
7 environment 700, program modules or other instructions that are depicted relative  
8 to computer 702, or portions thereof, may be fully or partially stored in a remote  
9 memory storage device. By way of example, remote application programs 760  
10 reside on a memory component of remote computer 750 but may be usable or  
11 otherwise accessible via computer 702. Also, for purposes of illustration,  
12 application programs 730 and other processor-executable instructions such as  
13 program modules 732 and operating system 728 are illustrated herein as discrete  
14 blocks, but it is recognized that such programs, components, and other instructions  
15 reside at various times in different storage components of computing device 702  
16 (and/or remote computing device 750) and are executed by data processor(s) 704  
17 of computer 702 (and/or those of remote computing device 750).

18 Although systems, media, devices, methods, procedures, apparatuses,  
19 schemes, techniques, approaches, procedures, arrangements, and other  
20 implementations have been described in language specific to structural, logical,  
21 algorithmic, and functional features and/or diagrams, it is to be understood that the  
22 invention defined in the appended claims is not necessarily limited to the specific  
23 features or diagrams described. Rather, the specific features and diagrams are  
24 disclosed as exemplary forms of implementing the claimed invention.

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